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Estimates of plant canopy attenuation, absorption and reflectance signatures and their relationships to select biophysical and biochemical features as determined by Optimal Passive Ambient Correlation Spectroscopy (OPACS).

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ESTIMATES OF PLANT CANOPY ATTENUATION, ABSORPTION AND REFLECTANCE SIGNATURES AND THEIR POTENTIAL TO ESTIMATE BIOPHYSICAL AND BIOCHEMICAL PLANT FEATURES

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ABSTRACT

Application of remote sensing technologies to ecosystem management requires a comprehensive understanding of radiative transfer theory and photon vegetation interactions at various spatial and temporal scales. As solar flux penetrates a plant canopy, absorption and scattering attenuate downward radiance and the light field diminishes. Biophysical and biochemical features of plant canopies that control attenuation include leaf area index, projected foliage coverage, leaf angle distribution, leaf moisture, chlorophyll, starch, cellulose, nitrogen and other organic and inorganic compounds. Field measurements of reflectance and bulk attenuation, transmission and absorption as a function of wavelength were made for canopies of live oak (*Quercus viriginiana*), Brazilian pepper (*Schinus terebinthifolius*) and grapefruit (*Citrus paradisi*) in east central Florida. Biophysical and biochemical analyses were conducted and Optimal Passive Ambient Correlation Spectroscopy (OPACS) was utilized to define optimal bands for use in predicting concentrations of biophysical and biochemical parameters.

1.0 INTRODUCTION

A primary objective for remote sensing in terrestrial ecology specifically and earth system science in general is determination of biochemical and biophysical features of vegetation, water, or land cover (Foody and Curran, 1994). Satellite and airborne remote sensing provide researchers access to spatial and temporal data necessary for

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development, parameterization and testing of local, regional, and global scale ecosystem risk and environmental process models. Subtle changes in ecosystem functioning may be expressed in plant canopy biochemical or biophysical properties as a result of altered metabolic processes, carbon allocation patterns, and nutrient availability (Hoobs and Mooney, 1989). The potential to remotely estimate canopy constituents depends partly on the influence of the parameter on the reflectance signature. Potential applications of remote sensing techniques that allow for spatial and temporal estimation of biophysical and biochemical conditions include agricultural land management, exotic plant control, ecosystem risk modeling, environmental impact quantification and wildlife habitat management.

Peterson, et al., (1988) and others described attempts to remotely sense biochemical constituents of leaves and forest canopies utilizing the visible and infrared regions of the spectrum. These authors focused on stepwise linear regression techniques to describe relationships between leaf chemical concentrations and reflectance data. In the laboratory, using dried samples, these methods produced results that compared reasonably well with error rates for wet chemical analysis techniques. Statistically significant regressions were demonstrated for protein, starch, sugar, lignin, nitrogen, total chlorophyll and cellulose (Peterson, et al.1988).

However, Fourty et al., (1996) reported that the empirical relationships elaborated on for one site or sample had poor predictive performance when applied to other samples, sites or years. This lack of robustness and consistency drives the need to develop more analytical based approaches to describe the relationships between canopy reflectance and its biochemical and biophysical features that contribute to the high degree of variability observed in empirical results. These features include canopy structural parameters such as leaf angle, projected foliage coverage, leaf area index, canopy depth, bottom reflectance or background characteristics and scattering and absorption processes that take place at the leaf level. Analytical approaches to the solution of these problems must be based on radiative transfer theory and the associated solution and inversion of some form of the radiative transfer equations describing absorption, scattering and transmission features of the medium (Asar and Myneni, 1990; Fourty et al., 1996).

The objectives of this study were to evaluate potential uses of the optimal passive ambient correlation spectroscopy (OPACS) method developeed by Bostater, (1992) for analysis of high resolution spectral reflection, absorption and attenuation signatures of leaves and plant canopies. The OPACS procedure utilizes an optimal band selection methodology, based on a nonlinear second derivative estimator, to define spectral regions of absorption or backscatter that can be utilized in biophysical parameter estimation (Bostater et al., 1994a;1994b).

2.0 MATERIALS AND METHODS

Three plant canopies, live oak (*Quercus viriginiana*), Brazilian pepper (*Schinus terebinthifolius*) and grapefruit (*Citrus paradisi*) were chosen for this study based on differences canopy and leaf structure. Spectral measurements of downwelling and upwelling irradiance were made at the top, bottom, and at various depths within each of the canopies using an SE590 high radiometric and spectral resolution solid state spectrograph with a 252 channel linear diode array. Each channel samples approximately 3 nm of the electromagnetic spectrum over the spectral range from 368 to 1110 nm. Data are used to calculate reflectance, transmittance, absorptance and attenuation and bottom reflectance. Leaf samples were collected from each canopy, a video image of the leaves on a white background was captured for estimation of leaf area. The leaves were placed on ice in the dark, and taken to the laboratory for spectral analyses. An estimate of nadir viewing projected foliage coverage was derived by collecting ten random video images in the perpendicular plane and analyzing them for percent sky visible in the frame.

Leaf-level measurements of transmittance and reflectance were made in the Marine and Environmental Optics Laboratory at Florida Institute of Technology using a simultaneous reflectance and transmittancemeasuring system designed by Bostater (1994b). Sub-samples consisting of 10 leaves of each species were used for simultaneous measurements of leaf reflectance and transmittance. The thickness of each leaf was measured, to be used as a path length estimate for calculating leaf-level absorption coefficients. Leaf tissue was then freeze-dried, ground, and analyzed for chlorophyll, TKN and metals.

Software developed by Bostater, (1992) was utilized to develop estimates of optimal spectral bands for estimation of biophysical and biochemical parameters. The approach produces an estimate of the analytical solution to the second derivative of the complex radiative transfer equation for reflectance providing information on $\mathbf{d^2R/d^2\lambda}$. (Bostater et al., 1994b). The second derivative inflection estimate is a precise measure of actual absorption or relative backscatter regions because it is based on three or more bands incorporating changes in spectral curvature.. The inflection estimator is defined as :

$$I(\lambda)_{m,i,n} = R^2(\lambda)_i / [R(\lambda)_{i-n} \times R(\lambda)_{i+m}] \qquad (1)$$

where $\mathbf{I_{(\lambda)}}$ is the inflection or second derivative estimator centered at band i calculated from the reflectance signature. **M** and **n** are forward and backward operators, respectively (Grew, 1980). The optimal channel located at **m, I, n** is determined by computing all possible combinations of **m, I, n** ranging from **i** = 2-251, **m** = 2-252, and **n** = 1-250 (Bostater et al., 1994b).

3.0 RESULTS AND DISCUSSION

The objective of this study was to evaluate the potential for utilizing the OPACS software for definition of optimal bands useful in developing remote estimates of biophysical and biochemical characteristics of plants at the canopy and leaf scale. Canopy and leaf level measurements of reflectance, transmittance and absorptance were developed for the three species. Differences in spectral signatures are a result of variability in canopy structure, bottom reflectance, and absorption and backscatter of leaves and other plant structures. For example, Figure 1 presents canopy reflectance and transmittance signatures for citrus, brazilian pepper and live oak stands.

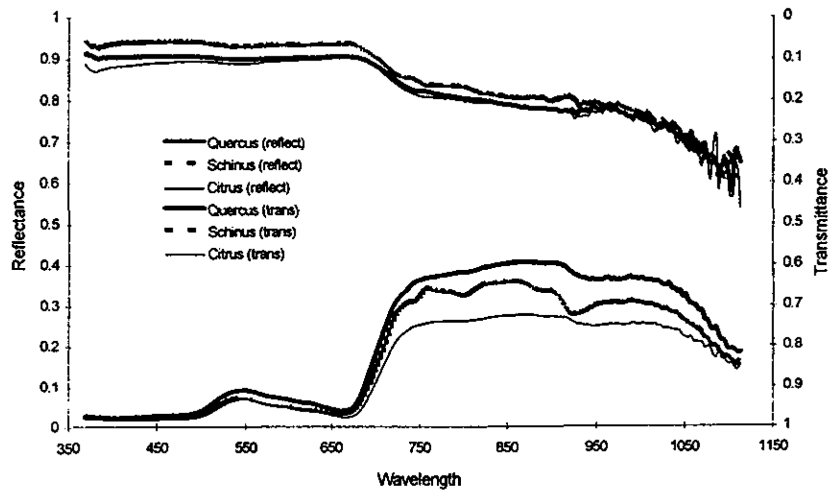

Figure 1. Example of reflectance and transmittance spectra for oak, citrus and brazilian pepper.collected at Kennedy Space Center in spring 1996. Note low values throughout photosynthetically active region between 400 - 700 nm.

Biophysical and biochemical measurements displayed subtle differences between the three canopies. Projected foliage coverage averaged 80% for citrus, 72% for oak and 66% for brazilian pepper. At a larger spatial scale citrus coverage would be lower than for the other species as a result of crown trimming and spacing between rows. This spacing issue may have contributed to the slight elevation observed in citrus transmittance estimates.

An example of OPAC analysis for total chlorophyll is presented in Fig. 2. Optimal bands were defined as 641, 697, and 1079 nm with a correlation of r = -0.81. The inflection point at 697 nm corresponds to the area of maximum chlorophyll absorption in the red region of the spectrum at the base of the red edge. Results of TKN analysis in general displayed weak correlation to the inflection estimates with most values below r = 0.70. The optimal bands were defined as 947, 1022, and 1088 nm with a correlation of r = 0.81.

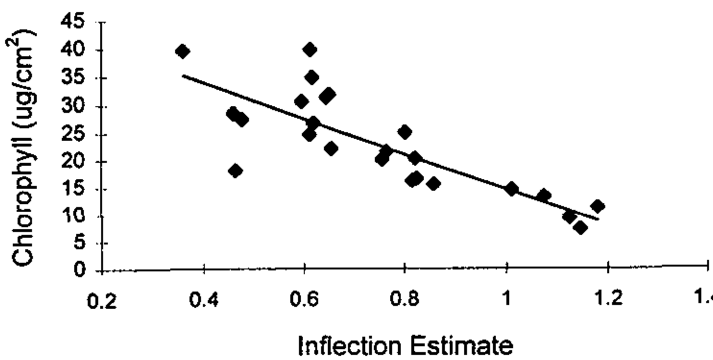

Figure 2. Example of OPACS derived relationship between the inflection estimate and chlorophyll concentration for oak species on Kennedy Space Center, Fl. in spring 1995.

From results obtained in this study the optimum bands selected with OPACS define the inflection or spectral curvature occurring in association with biochemical and biophysical based absorption or backscatter regions. The unique nature of the OPACS procedure with it's strong basis in radiative transfer theory suggests that it is an optimal approach for quantitatively analyzing and interpreting high resolution spectral signatures. More detailed evaluations need to be conducted to address sources of variance in the original reflectance signal such as changing projected foliage coverage, seasonal variability in leaf chemistry and shape, and influences of bottom reflectance from leaf litter, ground cover and soils. Further testing and development in a larger variety of landscape types and situations, including application to high spectral resolution data derived from aircraft and satellites is needed to continue refining and testing the applicability of the OPACS procedure.

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